Superluminal Motion in The interacting System of Electrons, Positrons and Photons

T. M. Gassym *

Physics Department, Middle East Technical University

06531 Ankara, Turkey

Institute of Physics Academy of Sciences of Azerbaijan Republic, Baku

Abstract

The coupled system of Boltzman equations for the interacting system of electrons, positrons and photons in high external electric ,$\vec{E}$, and arbitrary magnetic ,$\vec{H}$, fields is solved. The consideration is made under the conditions of arbitrary heating and the mutual drag of carriers and photons.

The non–stationary and non–uniform distribution function of photons for the all considered cases is obtained. It is shown that the distribution function of photons has the stationary limit for the drift velocities $(\vec{u}\vec{q}/\hbar\omega_q) < 1$ and grows exponentially with time for the drift velocities $(\vec{u}\vec{q}/\hbar\omega_q) \geq 1$. It is also shown that the mutual drag of carriers and photons leads to the formation of "quasi-particles"–the "electron dressed by photons" and "positron dressed by photons", i.e. the mutual drag plays the role of the dressing mechanism of carriers and leads to the renormalization of the mass and frequency of photons.

As a result of the analyses of the phenomena of coupling of the mutual drag system of carriers with the photons, we obtained some fundamental results: **a)** the finiteness of the mass of photon (i.e. the rest mass of the photons is not zero); **b)** reality of tachyons as a quasi–particles with a real mass in amplifying system (or regime); **c)** the mechanism of the theory of relativity and that of the Doppler effect which coincides with the renormalization of frequency or mass as a result of the mutual drag of carriers and photons at external field (force) are the same. These conclusions were obtained as a result of the fact that the relativistic factor enters the expressions of the distribution function of photons and other physical expressions in the first order in the form $\left[1-(u^2/c^2)\right]^{-1}$, but not in the form $\left[1-(u^2/c^2)\right]^{-1/2}$ as in Einstein's theory. Moreover, it is shown that the time delatation which is relativistic effect really takes place for the relaxation time of carriers or for the life time of carriers, or for the period of electromagnetic oscillations. The latter is a direct result of the

*e-mail: gassymt@newton.phycics.metu.edu.tr

Doppler effect. Also it is shown that the velocity of light is an average velocity of photons in the ground state, like the velocity of sound is the average velocity for the phonons.

1 Introduction

In my earlier publications I made a theoretical investigation of interacting system of electrons and phonons in semiconductors, semimetals and gaseous plasmas under high external electric and magnetic fields, and also when a strong electromagnetic wave propagating in the materials. In [1-4] the coupled system of kinetic equations for interacting electrons, holes and phonons under high electric and magnetic fields were solved by taking into account the arbitrary heating and the mutual drag of carriers and phonons. For the phonons, the solution of non–stationary kinetic equation was found and it was shown that the non–equilibrium and non-stationary distribution function of phonons has the stationary limit, when the drift velocity of coupled by the mutual drag system of carriers and phonons is less than the velocity of sound ($u < s$). For the drift velocities $u > s$, the distribution function of phonons grows exponentially with time. It corresponds to the generation of intrinsic phonons and amplification of phonons introduced to the system externally (the stream of phonons).

It was shown that the mutual drag leads to the renormalization of the frequency or the mass of carriers. As a result of the mutual drag, electrons and holes are "dressed" by phonons and forms "quasi–particles" which have the electron or hole charge ($\pm e$) and the phonon mass $m \simeq T_i/s^2$, where T_i is the temperature of the coupled mutual drag system of carriers and phonons)[1]–[5]. In weak electric fields, the mass of phonons is $m_0 \simeq T/s^2$. In the case of propagation of strong electromagnetic waves in semiconductors and semimetals under the external magnetic field, this leads to the cyclotron resonance of the "quasi–particles" with frequencies $\omega_H = (3/4)eH/\left[(T_i/s^2)c\right]$[5, 6]. It was shown[7] that the coupling of carriers and phonons as a result of their mutual drag is a general phenomenon. Actually, as it follows from [7], under the condition of longitudinal propagation of a strong electromagnetic wave in semimetals having equal electron and hole concentrations, the frequencies of Alfven and magneto–sound waves are equal to each other and have the form:

$$\omega_A = \omega_{ms} = kH/(4mN)^{1/2} = kv_A, \tag{1}$$

where $m = 4(T_i/s^2)/3$ is also so–called "mass of phonons". $T_i = T_i(+0)$–the effective temperature of the coupled by the mutual drag system of "electron + phonons" or "hole + phonons". Thus we may conclude that the mutual drag of carriers and phonons under external fields leads to the formation of compound particles ("quasi–particles", the carriers dressed by phonons) a with drift velocity $\vec{u}$.

In the first investigation[8], the degenerate semiconductors and semimetals in which weak electromagnetic waves propagates were considered. Particularly, in [8] the degenerate semiconductors having only one type of carriers were studied and the cyclotron resonance of the coupled system of electron + phonon was predicted. But soon after this work, it was shown[9] that this resonance is not observable because of the presence of impurities with a concentration $N_i = n$ (where n is the concentration of electrons). Also in the same work it was shown that in pure semimetals it is necessary to take into account the presence of two types of carriers which are drifted in opposite directions at $H = 0$. The remarks made on non–observability of the resonance in [9] applies also to the uniform and non–uniform low frequency cyclotron resonance in the degenerate semiconductors and in the semimetals with only one type of carriers when a strong electromagnetic wave propagates in the

materials[5, 6, 10]. These problems were discussed in[3, 5] and it was shown that in intrinsic semiconductors and semimetals both uniform and non–uniform cyclotron resonances in quasi–particle “hole + phonon” take place. In [3,5] it was also shown that such type of resonances are realized in non–degenerate impurity and intrinsic semiconductors and the question on their observability was discussed.

2 General Considerations

In the present paper the coupled system of kinetic equations for interacting system of electrons, positrons and photons in external high electric field $\vec{E}$ and arbitrary magnetic field $\vec{H}$ is solved. The non–equilibrium distribution functions of electrons, positrons and photons are obtained by taking into account their arbitrary heating and mutual drag.

For photons, the general solutions of non–stationary and non–uniform Boltzmann equations were found. The cases of weak ($\omega_H^{\pm}\tau_c \ll 1$), classically high ($\omega_H^{\pm}\tau_c \gg 1$), and quantizing ($\hbar\omega_H^{\pm} \gg T, T_c$) magnetic fields were considered. Here T is the initial temperature of equilibrium system (at $t = 0$, before the external fields are applied), $T_c(\vec{E}, \vec{H})$ is the temperature of heated electrons and positrons, $\omega_H^{\pm}$ is their cyclotron frequencies, and $\tau_c^{-1} = \nu_c$ is the relaxation frequencies of electrons and positrons (the photon produced by the annihilation of electron–positron pairs or by the scattering of electrons and positrons by photons). Also note that the index c stands for electrons,(e), and positrons,(p).

In the absence of or in a weak magnetic fields, the inter–carrier collision frequencies ν_{ee} and ν_{pp} are assumed to be much greater than the others, and that is why the isotropic parts of the distribution functions of carriers are assumed to be equilibrium one, with effective temperature of carriers $T_c = T_{e,p}(\vec{E}, \vec{H})$. This approximation corresponds to the case of high carrier concentrations, $n > n_{cr}$.

If the external field is a strong electromagnetic wave, then it is necessary to satisfy the following condition also:

$$\omega \gg \nu_\varepsilon^{\pm} \tag{2}$$

where $\nu_\varepsilon^{\pm}$ is the collision frequencies of carriers for the energy transfer to scatterers and ω is the frequency of the electromagnetic wave.

Under the condition (2), the isotropic parts of carrier distribution functions with $(\nu_\varepsilon^{\pm}/\omega)$ accuracy do not depend on time directly. By the direct solution of quantum kinetic equations in general case for the arbitrary spherical symmetric dispersion law of carriers, it was shown that under quantizing and classically high magnetic fields, the stationary distribution functions of carriers satisfying the boundary conditions, $F^{\pm}(\varepsilon) \mid_{\varepsilon\to\infty} = 0$ have the form (for the arbitrary quantities of their concentrations):

$$F^{\pm}(\varepsilon) = \left\{ const^{-1} exp\left(\int^{\varepsilon} \frac{d\varepsilon'}{T_c(\varepsilon', t)} \right) + 1 \right\}^{-1}, \tag{3}$$

here $T_c(\varepsilon, t) = A(\varepsilon, t)/B(\varepsilon)$ is the temperature of carriers which have occupied the energetic level ε and

$$A(\varepsilon,t)=(2\pi/\hbar)\sum_{\alpha\beta\vec{q}}C_q^2 \mid I_{\alpha\beta}^2 \mid (\hbar\omega_q^*)^2 N(\vec{q},t)\delta(\varepsilon_\beta-\varepsilon_\alpha-\hbar\omega_q)\delta(\varepsilon_\alpha-\varepsilon), \tag{4}$$

$$B(\varepsilon,t)=(2\pi/\hbar)\sum_{\alpha\beta\vec{q}}C_q^2 \mid I_{\alpha\beta}^2 \mid (\hbar\omega_q^*)^2 \delta(\varepsilon_\beta-\varepsilon_\alpha-\hbar\omega_q)\delta(\varepsilon_\alpha-\varepsilon),$$

where $\hbar\omega_q^*=\hbar\omega_q-\vec{V}\vec{q}$, C_q is the constant of interaction and $I_{\alpha\beta}$ is a matrix element for the transition from state α to state β and back (reverse).

For arbitrary degree of quantization we have:

$$F^{\pm}(\varepsilon)=\left\{1+\exp\left(\varepsilon-\zeta(\vec{E}\vec{H})/T_c\right)\right\}^{-1}, \tag{5}$$

$$T_c=T_i\left\{1+\left[\frac{V^{\pm}}{u}-1\right]^2(\varphi_1-1)\right\},$$

$$\varphi_1=\left[1-(\frac{u}{c})^2\right]^{-1/2}.$$

In the classical region of strong magnetic field we have:

$$T_c=T_i\left\{1+\frac{1}{3}\left(\frac{V^{\pm}}{c}\right)^2+\left(1-\frac{V^{\pm}}{u}\right)(\varphi_2-1)\right\}, \tag{6}$$

$$\varphi_2=\frac{c}{2u}\ln\left|\frac{c+u}{c-u}\right|,$$

here $V^{\pm}=cE/H$ is the Hall's drift velocity of carriers.

It was shown that for all cases considered the solution of non–stationary kinetic equation for the photons is:

$$N(\vec{q},t)=\left\{N(\vec{q},\vec{r}-\vec{u_0}t,0)+\beta\int_0^t d\tau\ N(\vec{q},\tau')exp\left(-\int_0^\tau \gamma_q(\tau')d\tau'\right)\right\} \tag{7}$$

$$exp\left(-\int_0^t \gamma_q(\tau)d\tau\right),$$

where $N(\vec{q},\vec{r}-\vec{u_0}t,0)$ is the initial distribution function of photons in the absence of electric and magnetic fields (at $t=0$), which in the case of uniform space is the equilibrium Planck's distribution function at temperature T. The increasing increment of photons is

$$\gamma_q=\beta\left(\frac{\vec{u}\vec{q}}{\hbar\omega_q}-1\right), \tag{8}$$

where $\beta=\beta_e+\beta_p+\beta_{ph}+\beta_b$ is the total collision frequency of photons with electrons, (e), positrons, (p), (including the photon decay to electron–positron pair), photons, (ph), and boundaries, (b), of the region occupied by the system, if such one exists.

$$\vec{u}(t) = \sum_{\pm} \overrightarrow{u^{\pm}}(t); \quad \overrightarrow{u^{+}}(t) = \frac{\beta_e}{\beta} \overrightarrow{V^{+}}(t); \quad \overrightarrow{u^{-}}(t) = \frac{\beta_p}{\beta} \overrightarrow{V^{-}}(t), \tag{9}$$

where $\overrightarrow{V^{\pm}}(t)$ is the average drift velocity of the carriers, $\overrightarrow{u^{-}}(t)$ is the drift velocity of the mutual drag system of "electron + photons" and $\vec{u}^{+}(t)$ is the same for the system of "positron + photons".

In general case, when the carriers are heated by a field of strong electromagnetic wave $\vec{E} = \overrightarrow{E_0} e^{-i\omega t} + \overrightarrow{E_0^*} e^{i\omega t}$, $\overrightarrow{V^{\pm}}(t) = \overrightarrow{V^{\pm}} \cos\omega t$ we have

$$N(\vec{q},t) = \left\{ N(\vec{q},0) + \beta \int_0^t d\tau N(\vec{q},\tau) exp\left(\beta \left[\tau - \frac{\vec{u}\vec{q}}{\hbar\omega_q} \frac{\sin\omega\tau}{\omega} \right] \right) \right\} \tag{10}$$
$$exp\left(-\beta \left[t - \frac{\vec{u}\vec{q}}{\hbar\omega_q} \frac{\sin\omega t}{\omega} \right] \right).$$

In the case of constant external electric field ($\omega \to 0$) we have:

$$N(\vec{q},t) = \left\{ N(\vec{q},0) - \frac{N(\vec{q},T_i)}{1 - \vec{u}\vec{q}/\hbar\omega_q} \right\} exp\left(\beta \left[\frac{\vec{u}\vec{q}}{\hbar\omega_q} - 1 \right] t \right) + \frac{N(\vec{q},T_i)}{1 - \vec{u}\vec{q}/\hbar\omega_q}, \tag{11}$$

here $T_i = (\beta_c/\beta)T_c + (\beta_{ph}/\beta)T_{ph} + (\beta_b/\beta)T_b$ is the temperature of the mutual drag system of coupled heated carriers and photons.

We have still considered the case when the initial state of the photons ($t = 0$) was assumed to be equilibrium state without any preferred direction. If the initial distribution part of the photons has directional drift (the photon stream), then the solution of the kinetic equation for photons has the form:

$$N(\vec{q},\vec{r},t) = \left\{ N(\vec{q},\vec{r} - \overrightarrow{u_0}t, 0) + \beta N_i(\vec{q},T_i) \int_0^t exp\left(\beta \int_0^\tau \left[1 - \frac{\vec{u}\vec{q}}{\hbar\omega_q} \right] d\tau' \right) d\tau \right\} \tag{12}$$
$$exp\left(-\beta \int_0^t \left[1 - \frac{\vec{u}\vec{q}}{\hbar\omega_q} \right] d\tau \right).$$

As it follows from (12), the solutions of the uniform and non–uniform equations for the photons have the same form corresponding to the different initial conditions. Therefore, if the initial distribution function of photons has the form of the drifted Planck's distribution function $N(\vec{q},\vec{r} - \overrightarrow{u_0}t, 0)$ and if the external field is uniform, then this non–uniformity has to be preserved with time and the drift at external field has to be added to them. Thus the equation (12) allows us to consider the processes of absorption or amplification of photons introduced to the system from outside (initial stream of photons), and the generation of intrinsic photons of system in external field. In principle it is the most common form of the initial distribution function, which is taking the chance for examination of the affirmation of the special theory of relativity about equivalency of all the inertial frames of reference. Actually, by the transition to the frame of reference drifting jointly with photons, as a result, we have the Planck's equilibrium distribution function at the temperature T in this frame of reference. In other words, in the absence of external fields ($E = H = 0$), from

the kinetic equation, for initially non–uniform system of photons we obtain uniform one, by the transition from one frame of reference to another one but it does not mean that the two frames of reference are equivalent.

In fact, the transition from the frame of reference drifting jointly with the photons having velocity $\overrightarrow{u_0} = c\vec{q}/q$ to the frame of reference in which the photons are at rest is equivalent to the transition from one inertial frame of reference with $u = u_0$) to the other with $u = 0$. As a result we obtain $N(\vec{q}, \vec{r} - \overrightarrow{u_0}t, 0) = N(\vec{q}, 0) = N_0(\vec{q}, T)$, for all moments of time, solution (12) transforms to (11) but it does not mean that these two frames of reference are equivalent. In other words, the demand of equivalency of the laws of Physics in that two inertial frames of reference is equivalent to the demand of the equivalency the equilibrium Planck's distribution function to the drifted Planck's distribution function or to the demand of equivalency of the laws of Physics in the uniform and non–uniform cases (or spaces).

As one can see from (7), (11) and (12), the general solution of non–stationary equation of photons has the stationary limit in the region of drift velocities $(\vec{u}\vec{q}/\hbar\omega_q) < 1$,

$$\lim_{t\to\infty} N(\vec{q}, t) = N(\vec{q}) = N(\vec{q}, T_i)\left(1 - \frac{\vec{u}\vec{q}}{\hbar\omega_q}\right)^{-1}. \tag{13}$$

As it follows from the equations (7), (11) and (12), for the drift velocities $(\vec{u}\vec{q}/\hbar\omega_q) > 1$ the distribution function of photons grows exponentially with time. It corresponds to the generation of intrinsic photons by the increment of grow γ_q and the amplification of photons introduced to the system from outside (stream of photons) by the coefficient of amplification

$$\Gamma_q = \frac{\gamma_q}{c} = \frac{\beta}{c}\left(\frac{\vec{u}\vec{q}}{\hbar\omega_q} - 1\right) = \frac{\beta}{c}\left[\frac{u}{c}\cos\alpha - 1\right], \tag{14}$$

here $\alpha = \widehat{\vec{u}\vec{q}}$ is the angle between drift velocity of the coupled by the mutual drag system "electron + photons" ("the dressed electron") or "positron + photons" ("the dressed positron") and the momentum of photon.

In the case of the propagation of strong electromagnetic wave and in the presence of external magnetic field, the current of electrons and positrons has the form:

$$\overrightarrow{j_\pm} = ne\overrightarrow{V^\pm}. \tag{15}$$

where $\overrightarrow{V^\pm} = \langle\overrightarrow{V^\pm}(\varepsilon)\rangle$ is the average drift velocity of the carriers. Here

$$\overrightarrow{V^\pm}(\varepsilon) = \mp\frac{e\ \Omega_\pm(\varepsilon)}{m_c}\frac{\overrightarrow{E_\mp}\left(\omega_H^\pm/\Omega_\pm(\varepsilon)\right)\vec{h}\vec{E} - \left(\omega_H^\pm/\Omega_\pm(\varepsilon)\right)^2\vec{h}(\vec{h}\vec{E})}{\Omega_\pm^2 - (\omega_H^\pm)^2}, \tag{16}$$

$$\vec{h} = \vec{H}/H, \quad \Omega_\pm\left(\langle\varepsilon\rangle\right) = \omega + i\nu^\pm\left(\langle\varepsilon\rangle, u\right),$$

$$\nu_{ph}^\pm\left(\langle\varepsilon\rangle, u\right) = \nu_{ph}^\pm(T_i)\left(1 - \frac{u\left(\langle\varepsilon\rangle\right)}{V^\pm\left(\langle\varepsilon\rangle\right)}\right).$$

In the case of $\omega \to 0$, and $\vec{E}\|\vec{H}$ (or $H = 0$) we have:

$$\overrightarrow{V}^{\pm}(\langle\varepsilon\rangle) = \frac{e\vec{E}\beta_c}{m_c\nu_{ph}(\langle\varepsilon\rangle, u)\,\beta_{ph,b}} = \frac{e\vec{E}}{m\,(T_i, u)\,\beta_{ph,b}}. \tag{17}$$

Here $m = m_c\nu_{ph}(\langle\varepsilon\rangle, u)/\beta_c$ is the mass of the coupled by the mutual drag system of carriers and photons and $\beta_{ph,b} = \beta_{ph} + \beta_b$.

Actually, the interacting system of heated electrons, positrons and photons in the stationary state $(\vec{u}\vec{q}/\hbar\omega_q) < 1$ under external high electromagnetic, and the classically high or the quantizing magnetic fields as a result of their mutual drag has a cyclotron resonance with frequencies

$$\omega_H^{\pm} \simeq \frac{eH}{m(T_i)c} = \frac{eH}{(T_i/c^2)\,c}. \tag{18}$$

As it is seen from the equation (16), the resonance takes place with frequencies of electromagnetic wave less than the collision frequencies of photons with carriers. The width of the resonance lines are defined by the expression

$$\gamma = (3/2)\left[\left(\omega^2/\beta_c\right) + \beta_{ph} + \beta_b\right]. \tag{19}$$

In other words, as a result of the mutual drag, the electrons and positrons become composite particles (the coupled system of "electron + photons" and "positron + photons" i.e. so–called "dressed" by the photons "quasi–electron" or "quasi–positron" with an effective mass $m(T_i)$. In fact, we obtain the quasi–particle with the electron's or positron's charge and the photon's mass

$$m(T_i) = m(E, H) = T_i/c^2, \quad \langle E\rangle = T_i = m(T_i)c^2. \tag{20}$$

Since T_i and T mean the average kinetic energy, then from the equations (13), (14) and (18), we obtain that the so–called "velocity of light" in vacuum c is the average velocity of photons in the equilibrium or stationary state at temperature T. The "dressing" of electrons and positrons in quantum electrodynamics was connected with the virtual absorption and emission of photons by electrons and positrons which occupies the given level of energy, i.e. with the finiteness of the lifetime of electrons and positrons or the natural width of the given energetic level. For the interacting system of electrons, holes and phonons in semiconductors, semimetals and gaseous plasmas, the analogous problem was solved in[1]–[5].

As it follows from (7), (11), (12) and (13), under the external electric and magnetic fields and under stationary conditions, the relativistic factor enters the distribution function of photons in the first order $[1 - (\vec{u}\vec{q}/\hbar\omega_q)]^{-1}$ instead of the form $[1 - (v^2/c^2)]^{-1/2}$ in the relativistic electrodynamics. This is connected with the violation of time symmetry $(t \to -t)$ of equations in electrodynamics and, in common dynamics when there exists external fields. In this case the uniformity of the space and as a result, the law of the conservation of momentum is violated too. Since the external fields act continuously but not instantaneously we have a motion with acceleration and the oscillatory regime is absent. The substitution $t \to -t$ does not lead to the simple substitution $\vec{v} \to -\vec{v}$, because the motions along and in the opposite of the field direction are different and do not compensate each other.

The relativistic factor of the form $[1-(v^2/c^2)]^{-1}$ may appear only in the absence of the external field or in the weak external field in equilibrium or stationary conditions, by using the isotropic part of the distribution function of photons. Actually, by the separation of the stationary distribution function of photons (13) into the isotropic and anisotropic parts we have:

$$N(q) = N_s(q) + N_\alpha(q) = N(q,T_i)\left(1-\frac{u^2}{c^2}\cos^2\alpha\right)^{-1} + N(q,T_i)\frac{u}{c}\cos\alpha\left(1-\frac{u^2}{c^2}\cos^2\alpha\right)^{-1}. \tag{21}$$

Since as a result of the mutual drag, the carriers and photons form the coupled system (complex) with a common drift velocity then under the conditions of strong (full) mutual drag $\alpha = 0$ or π and we obtain:

$$N_s(q) = N(q,T_i)\left[1-\frac{u^2}{c^2}\right]^{-1}, \quad N_\alpha(q) = \left(\frac{u}{c}\cos\alpha\right)N(q,T_i)\left[1-\frac{u^2}{c^2}\right]^{-1}. \tag{22}$$

In the absence of external electric and magnetic fields, in the general case $u = u_0 = const$ and we have:

$$N(\vec{q},\vec{u_0}) = N(\vec{q},\vec{r}-\vec{u_0}t,0) = \left\{exp\left(\frac{\hbar\omega_q^*}{T}\right)-1\right\}^{-1}, \tag{23}$$

and $\hbar\omega_q^* = \hbar\omega_q - \vec{u_0}\vec{q}$. By the transition to the frame of reference drifting together with photons, we can obtain from (21) the equilibrium Planck's distribution function with temperature T. Let us discuss the main question now: may the presence of the relativistic factor of the first or the arbitrary order lead to any singularities in physical phenomena or quantities? As it follows from the non-stationary solution of the distribution function of photons (11) or (12), the Lorentz–Einstein theory corresponds to uniform (equilibrium) case and must satisfy the stationary condition $v/c < 1$! The case of $v = c$ is not included in their theory and therefore the conclusions of the Einstein's theory about being the rest mass of photons equal to zero and c being the ultimate velocity of propagation of all types of interaction in nature do not have the real basis.

Actually, from general solution of the non–stationary kinetic equation of the photons (11), by expanding the exponent into series near the point $\vec{u}\vec{q}/\hbar\omega_q = 1$ we have

$$\begin{aligned} N(\vec{q},t) &= \left\{N_0(\vec{q},T) + \frac{\beta N(\vec{q},T_i)}{\gamma_q}\right\}\left\{1+\gamma_q t + \frac{1}{2}(\gamma_q t)^2 + \ldots\right\} - \frac{\beta N(\vec{q},T_i)}{\gamma_q} \\ &= \{N_0(\vec{q},T)(1+\gamma_q t) + N(\vec{q},T_i)\beta t\} + \frac{1}{2}\left\{N_0(\vec{q},T)(\gamma_q t)^2 + \beta\gamma_q N(\vec{q},T_i)t^2\right\}. \end{aligned} \tag{24}$$

At the point $\gamma_q = 0$ we have

$$N(\vec{q},0) = \lim_{\gamma_q\to 0} N(q,t) = N_0(\vec{q},T) + N(q,T_i)\beta t. \tag{25}$$

As it follows from the expressions (24) and (25), at the point $\vec{q}\vec{u}/\hbar\omega_q = 1$, i.e. at the point $u = c$ the distribution function of photons is non-stationary and grows linearly with time and the singularity is canceled!

Since the Einstein's theory is a stationary one, it is not applicable to the non–stationary conditions, namely to the region of drift velocities $v \geq c$ or $u \geq c$. For the drift velocities $v \geq c$ or $u \geq c$ the theory must be non–stationary. The Einstein's theory is a one mode theory and that is why it must be obtained from the many particle (or many mode) theory by the limiting transition to the one mode case. The effect of coupling of charged carriers and photons as a result of their mutual drag is a common phenomenon. It is a reaction of the system on action of external fields for the conservation of the stationary state of system (the analog of "self–conservation" in biology). Thus we have found the "dressing" mechanism of charge carriers used earlier in quantum electrodynamics.

3 Conclusions

As a result of analyses of the phenomena of coupled system of charge carriers and photons, by using the equations (7),(10)-(13) and (20) we reach the following conclusions:

1. As it follows from the non–stationary distribution function of photons the Lorentz-Einstein theory corresponds uniform space (equilibrium) case and it must satisfy the stationary condition $v < c$! The case of $v = c$ is not included in their theory. At the point $u = c$ (i.e. $\gamma_q = 0$), the distribution function of photons (23) is non–stationary, does not have any singularity and grows linearly with time.

For this reason, the conclusions of the theory of relativity that the rest mass of photons is zero and c is the ultimate velocity for the propagation of all types of interactions in nature do not have the real basis.

2. The Einstein's theory was a one mode theory and that is why must be derived from the many body (mode) theory by limiting transition to the one mode case at $v < c$. For the $v > c$ or ($u > c$) cases the theory must be non–stationary. As we say the mutual drag leads to the formation of "quasi–particles", the electron or positron "dressed" by photons. The average energy in stationary state $u < c$ for the one mode case is:

$$\begin{aligned}\langle \varepsilon \rangle = \langle \hbar\omega \rangle \langle N_i(q, T_i) \rangle &\approx \frac{T_i \langle N(\omega, T_i) \rangle}{1 - u^2/c^2} \\ &= \frac{T \langle N(\omega, T_i) \rangle}{1 - u^2/c^2} \frac{T_i}{T} = \frac{M_0 c^2}{1 - u^2/c^2} \left(\frac{T_i}{T} \right)^2 .\end{aligned} \tag{26}$$

The mass of the heated photons for one mode is:

$$M_i = \frac{M_0}{1 - u^2/c^2} \left(\frac{T_i}{T} \right)^2 . \tag{27}$$

The mass of one heated photon is:

$$m = \frac{M_i}{\langle N(\omega, T_i) \rangle} = m_0 \frac{T_i}{T} \left(1 - \frac{u^2}{c^2} \right)^{-1} . \tag{28}$$

In the absence of heating, the average energy is:

$$\langle\varepsilon\rangle = Mc^2 = \langle N_0(\omega,T)\rangle \frac{T}{1-u^2/c^2} = M_0c^2\frac{1}{1-u^2/c^2} \tag{29}$$
$$= m_0c^2\frac{\langle N_0(\omega,T)\rangle}{1-u^2/c^2}, \quad m = \frac{m_0}{1-u^2/c^2},$$

where $m_0 = M_0/\langle N_0(\omega,T)\rangle \simeq T/c^2$ is the rest mass of photon, i.e. the mass of photon in the frame of reference which is drifted with photons at temperature T, and $\langle N\rangle$ is the concentration of photons for one mode.

3. As it follows from (26) under high electric and magnetic fields for drift velocities $u < c$, the energy (or the mass) of photons for one mode grows as a result of the mutual drag, as well as the heating of the carriers and photons.

4. As it follows from (7)-(13) under the external electric and magnetic fields, the relativistic factor enters the expressions of the distribution function and other physical quantities in the first order as $(1-u^2/c^2)^{-1}$, instead of $(1-v^2/c^2)^{-1/2}$ in Einstein's theory. This together with the conclusions 1 and 2 solves the main problem of super–luminal particles named–tachyons, because in our theory the imaginaricy of the mass of tachyons is liquidated.

5. There is an opinion that the original conception about tachyons, as individual particles such as electrons, protons and etc. is not correct and the tachyons in such understanding is absent[11]. **Our investigations show that the ordinary particles such as electrons, positrons and also like photons may stand as super–luminal under high external fields in the condition of mutual drag**. Also there is an opinion that the tachyons as an elementary excitations (quasi–particles) there exists widely in complex systems which loss its stability and made an phase transition to a stable state[11]. In origin the tachyons, in general, were considered only in amplifying mediums[12]–[15]. **As it is seen from our investigations actually for drift velocities greater than the speed of light, the super–luminal particles generate or amplify the electromagnetic waves (photons) and the super–luminal particles are placed in the regime of generation or amplification independently of the type of medium (see also[16])**. As it will be shown in a special report, in general all elementary excitations including so–called "elementary particles" are quasi-particles.

6. At the point $u = c$ the angle α between $\vec{u}$ and $\vec{q}$ is equal to $\pi/2$ and we have the condition that the electromagnetic wave becomes free and is emitted. Thus the point $u = c$ is the point of transition of the system from the absorption regime to the regime of emission of electromagnetic waves (photons).

7. It is shown that the relativistic expression for the deceleration of time really takes place for the relaxation time of carriers and photons, for the life–time of carriers and also for the period of electromagnetic oscillations. Actually, in dynamics and electrodynamics the time enters the relations as a parameter, but not as a free coordinate and for this reason the Einstein's relation is impossible to apply to the time. Since $\tau^{-1} \sim N_i(q,T_i)$ we have

$$\tau_i \approx \tau_0(1-u^2/c^2)(T/T_i), \quad l_i = u\tau_i = l_0(1-u^2/c^2)(T/T_i). \tag{30}$$

If $T_i = T$ we have:

$$\tau_i \approx \tau_0(1 - u^2/c^2), \quad l = l_0(1 - u^2/c^2). \tag{31}$$

8. It is shown that the so–called "speed of light" in vacuum c, like the velocity of sound for phonons, is an average velocity of photons in the ground state.

9. As it follows from (7), (10), (11) and (13) at the point $u = c$ the distribution function of photons is an isotropic one and the anisotropy part of the photon distribution function at this point is zero. It means that the ground and the stationary states of electromagnetic field is spherically symmetric (this question will be discussed in a special report). At the point $u = c$ the rate of the stimulated absorption and emission are equal to each other and there is only spontaneous emission of photons and dissipation is absent.

10. It is shown that the demand for the invariance of the Maxwell equations or the laws of Physics in all inertial frames of reference is not correct. It is equivalent to the demand of invariance of laws of Physics in the uniform and non–uniform spaces or to the demand of equivalency of physical laws in cases of the presence and absence of external field (force).

11. It is shown that the presence of the second inertial frame of reference moving with a constant drift velocity relative to the first one may be a result of the presence of space non–uniformity or the uniform external field.

Actually in the uniform space because of the equivalency of all the points of space, it is impossible to have simultaneously two or more inertial frames of reference with different constant drift velocities with respect to each other. Because it will lead to the violation of the space uniformity, i.e. the change of the distance r_{12} between the initial points of that frames of reference ($r_{12} \neq const.$). In the uniform space, for the conservation of the space uniformity during the motion it is necessary that the motion of all points of the space must be the same constant velocity (in the absence of the external field), or with the constant acceleration (in the presence of the uniform force). For both cases the frames of reference, connected with the different points of the space, do not have the motion relative to each other without the violation of the space uniformity or the uniformity of the external force. Since all points of the space in both cases are placed on the same conditions and are equivalent. To choose two frames of reference moving with constant drift velocity with respect to each other, it is necessary to have the space, which consists of two or more sub–spaces. All points of the first sub–space are at rest or have the motion with the constant velocity v and all points of the second sub–space move with a constant acceleration. The first of them is inertial, but the second accelerates and ,for this reason, the demand of equivalency of laws of Physics in that two frames of reference are equivalent to the demand of the equivalency of the first and the second Newton's laws. This demand is absurd, of course!

12. As it follows from (7)–(12) the demand of the equivalency of the laws of Physics in all inertial frames of reference for the photons is equivalent to the demand of the equivalency of the Planck's equilibrium distribution function to the drifted Planck's distribution function.

13. It is shown that at the external electric fields $E < H$, the drift velocity of carriers $u < c$ and the energy received from external field is accumulated by the coupling of carriers with photons, as a result of the mutual drag (as a result of the construction of structure by the mechanism of "dressing of carriers with photons") and stationary state is conserved. In this region of drift velocities the absorption is greater than the emission. Under the condition $E > H$ i.e. at the drift velocities $u > c$, the generation and amplification

dominates and the number of photons grows exponentially with the time. **The violation of the stationary state begins from the point $u = c$ and from this point it begins that the transition of the carriers "dressed by photons" to the following stationary state by the reactive emission of photons back**. In the region of drift velocities $u > c$, the anisotropic part of the photon distribution function is much more than the isotropic one. **Thus in our investigation the mechanism of the transition of particles to the following stationary state is obtained.**

14. It is shown that for the drift velocities $u > c$ so–called energy (or mass) for one mode is:

$$\begin{aligned}\langle\varepsilon\rangle &= \left(\frac{T_i}{T}\right)^2 \frac{T\langle N(q,T)\rangle}{(u/c)-1}\left\{[\exp(\gamma_q t)-1]+\frac{T}{T_i}\exp(\gamma_q t)\right\} \\ &= \frac{M_0 c^2}{(u/c)-1}\left(\frac{T_i}{T}\right)^2\left\{[\exp(\gamma_q t)-1]+\frac{T}{T_i}\exp(\gamma_q t)\right\},\end{aligned} \tag{32}$$

or the mass for one mode is:

$$M = \frac{M_0}{(u/c)-1}\left\{[\exp(\gamma_q t)-1]+\frac{m_0}{m(T_i)}exp(\gamma_q t)\right\}. \tag{33}$$

In the absence of heating

$$M = \frac{M_0}{(u/c)-1}\left[2\exp(\gamma_q t)-1\right] \approx \frac{2M_0}{(u/c)-1}\exp(\gamma_q t). \tag{34}$$

As it follows from these equations the mass of photons for one mode in the region of drift velocities $u > c$ grows exponentially in time.

The case considered by Einstein may correspond to the case when the first of the chosen frame of reference is connected with the photons and drifted together with them and the second is connected with the charged carriers (electrons or positrons) drifted with constant velocity relative to first one. Here the photons (electromagnetic field) play the role of media and the charged carriers drifted relative to that media. Thus the system must consists of three subsystems. Actually, in electrodynamics the space (or the system) is consists of three sub–space (or subsystems): the sub–space of negatively charged carriers, sub–space of positively charged carriers and the other sub–space (or space) of photons. For this reason, the electrodynamic space is non–uniform initially, because the point of space where negatively charge carrier is placed is not equivalent to the point of space where the positively charged carrier is placed and both are not equivalent to the point where the photon is placed. The presence of the two type of charge leads to the presence of so–called Lorentz force. The condition of stationarity of the ground state is the equality of this force to zero $F = 0$! This condition corresponds to the annihilation of charge carriers with production of photons, i.e. production of free electromagnetic field without charges. It means that the space of photons (i.e. free electromagnetic field) can decay to the two sub–spaces: the spaces of the negative and positive charges and also two sub–spaces of negative and positive charges can produce the space of photons (the electromagnetic space or media).

As it follows from our investigations, the case studied by Lorentz and Einstein corresponds to the case of the presence of weak external field when the heating of carriers

and photons is absent and there is only their mutual drag. Also they considered the case of one type of charge carriers. In the presence of mutual drag of the electrons and photons, the distribution function of photons $N(q)$ has the form of Planck's function displaced with a constant drift velocity and as a result with the renormalized frequency of emission $\omega_{em} = \omega_q^* = \omega_q - \vec{u}\vec{q}/\hbar$. For the drift velocities $u < c$, ω_{em} decreases with the increasing drift velocity u because the stationary distribution function of photons has the form (23) or (13).

Thus in the second frame of reference, charge carrier emits or absorbs photon with a frequency $\omega_{em} = \omega_{obs.}[1 - \vec{u}\vec{q}/\hbar\omega_{obs.}]$. In the one mode case for the observed frequency we have $\omega_{obs.} = \overline{\omega} = T_i/\hbar = cq/\hbar$. In other words

$$\omega_{obs.} = \omega_{em}\left(1 - \frac{u}{c}\cos\alpha\right)^{-1}, \quad \lambda_{obs.} = \lambda_{em}\left(1 - \frac{u}{c}\cos\alpha\right). \tag{35}$$

For the case when the both frames of reference are assumed to be inertial one, i.e. they move along one line (along the x–axis) $cos\alpha = 1$ and we have

$$\omega_{obs.} = \omega_{em}\left(1 - \frac{u}{c}\right)^{-1}, \quad \lambda_{obs.} = \lambda_{em}\left(1 - \frac{u}{c}\right). \tag{36}$$

As it follows from these equations, the Doppler effect is also a result of the mutual drag of carriers and photons. Actually the source of the emission (charge carrier) drifts relative to frame of reference connected with the photon (observer) with the drift velocity $\vec{u}$. By increasing of drift velocity $\vec{u}$ the distance between the source and the detector is increased too and ,as a result, the observed frequency of photons is increased or the wavelength is decreased. In the opposite case, the wavelength is increased. In the region of $u < c$ the source (the charge carrier) moves slower than the detector (photon) and as a result the distance between them is decreased and the wavelength of observed photons (light) is increased. Thus the mutual drag of electrons and photons in the region $u < c$ leads to decreasing the frequency of emission or absorption (see "Low frequency cyclotron resonance for the phonons" [2, 5, 8]). It means that the frequency of the observed light (photons) is increased.

15. As it follows from the present consideration the so–called relativistic phenomena and the Doppler effect are the same ones and are a result of the mutual drag of interacting system of carriers and photons under external field. The case was considered by Lorentz and Einstein corresponds to the case, when the charge carriers are drifted under electromagnetic field at the conditions of the mutual drag of carriers and photons in the absence of their heating by the field.

The distinction between the results of the theory of relativity and the Doppler effect is related with the fact that the Doppler effect deals with the total stationary distribution function whereas the theory of relativity deals only with its isotropic part. In other words, the Doppler effect is obtained as a result of taking into account the violation of the time–symmetry at the external field.

4 The Superluminal Motion

In 60's and at the beginning of 70's years the problem of possibility of superluminal motion was a subject of wide spread discussions[17]. The hypothesis on the existence of superluminal particles–tachyons–was introduced in [15]-[20]. Although, the special theory of relativity does not strictly outlaw tachyons. in order to remain within the demands of the special theory of relativity, it was necessary to ascribe the imaginary mass (im_o) for tachyons. But, the imaginary mass of tachyons does not call a great anxiety. More complexities were connected with the principle of causality. There was witty but unsuccessful attempts to reconcile the existence of tachyons with the causality principle[15, 19]. At that time there was no experimental evidence for tachyons. Therefore, the interest in tachyons disappeared slowly.

In 1965, a physical object moving with superluminal velocity was realized. It was a pulse of light with stationary semblance moving through the amplifiered laser with a velocity greater than the speed of light in vacuum[20]-[22]. The propagation velocity of the light pulse through the amplifier exceeded the vacuum speed of light by 6–9 times.

In 1970, Garrett and McCamber[23] asserted that the concept of group velocity is meaningful only in an absorptive medium. The conclusion was based on the simulations of Gaussian pulses propagating in a medium which has resonance centered on the narrow spectrum of the pulse. They found that the peak of pulse can travel the medium with apparent superluminal velocities and even leaves the medium before the original peak enters the medium, i.e. negative velocity. This took place even the pulse maintained a semblance of its original temporal profile, albeit attenuated, allowing for an unambiguous assessment of travel time of pulse. They explained this interesting event which seemed to be in contradiction with the theory of special relativity and the principle of causality, in terms of pulse reshaping where the latter portion of the pulse is preferentially attenuated so that the pulse appeared to move forward with a excessive speed, which agreed with the group velocity.

In 1974, a paper was published[24] in which the superluminal motions were connected with the motion of excitations in unstable media which loses its stability and makes phase transition into more stable state. As an example of the unstable media mentioned, the authors discussed in a paper[25] too. The idea about superluminal motions in unstable media were developed in [25]. As it follows from our theory, electrons and positrons generate or amplify the photons with superluminal velocities in nonstationary or unstable regime.

In 1982, S. Chu and S. Wong[26] confirmed the predictions of Garret and Mc Camber by measuring the transmission time of laser pulse turned to a resonance in GaP:N. In particular, the physical relevance of group velocity was affirmed in the superluminal and negative cases.

At Berkeley, Steinberg, Kwiat and Chiao[27, 28] have experimentally showed that individual photons penetrate into optical tunnel barrier with a group velocity considerably greater than the vacuum speed of light. In the papers[29, 30], R. Chiao et al. reported that in simulations of pulse propagation in amplifier media, near gain resonances similar exotic behavior is expected. Several experiments on photonic tunneling observed in microwave and optical regions showed the superluminal signal and energy velocities violating Einstein causality. Superluminal group velocities have been experimentally observed for propagation through an absorbing medium[26], for microwave pulses[31, 33] and for light transmitted

through a dielectric medium[27, 28, 29, 34]. These experiments demonstrates the superluminal nature of the tunneling process. Tunelling is one of the most mysterious phenomena from quantum mechanical point of view. Yet it is one of the most basic and important process in nature. It may seem that all that we want to know about the tunneling is now well understood as given in the present mature of quantum theory. However, there remains an open problem concerning the mechanism and duration of the tunneling process, i.e. the question: "How long does it take for the particle to tunnel across the barrier?". This question first addressed in 1930's[35] is still the subject of much controversy, since the numerous theories contradict each other in their predictions for the tunneling time. Actually some of them as most notable Wigner's theory predict that this time should be superluminal[36], but others predict that it should be subluminal[37, 38]. Thus, the first answer that the group delay (also known as the "phase time") can in certain limits be paradoxical small, implying barrier transversal at a speed greater than that of light in vacuum[35, 36].

Apart from its fundamental interest, a correct theoretical and experimental solution of this problem is important from general point of view and for the determining the speed of devices which are based on tunneling. Prof. R. Chiao[39] states that "... The many manifestations of tunneling and the many applications to devices strongly motivated us to examine the unsolved tunneling time problem experimentally." It is very important to attack to state precisely at the outset the operational definition of the quantity being measured. For their experiments, the "tunneling time" was that type of quantity.

The photonic tunneling experiments in microwave and optical regions have revealed superluminal signal and energy velocities[27, 28, 31]. There is a opinion that the photonic tunneling violates the Einstein causality[40]. The measured velocity tunneled signal was $4.7c$ for the microwave[28] and $1.7c$ for single photon[27, 28] experiments.

Recent experiments were carried out by using three examples of photonic barriers: an undersized wave guide between two normal guides, a periodic dielectric heterostructure (often called a one dimensional photonic lattice) and double prism with a gap of rarer refractive index acting as a photonic barrier. Latter set up described as frustrated total internal reflection.

Let us now present the results of experiments carried out in 1965 by Bassov et al. which are very important in theoretical point of view. At the beginning of 60's arised the problem of receiving the high energy pulses in time interval about 1 nanosecond. For this purpose, a short pulse of light is obtained with the help of so–called giving generator and amplified by an amplifier laser[12, 21, 22]. The schematic description of the experimental set up is as follows: The pulse of light obtained from the giving generator splits into two parts. First, more powerful part propagated through the amplifier and the second part propagated through the air and played the role of the registration target. Both of the pulses were received by the emission receivers. The signals of the receivers were sent to the oscilloscope for visual observation. There was an expectation that the pulse propagated through the air must have a speed greater than that of the pulse propagated through the amplifier. Moreover, there was a prior expectation that together with the increasing of the amplitude of the pulse propagated through the amplifier, its form must also change. The real results of the experiment were surprising and leaded to some confusions. The pulse propagated through the amplifier did not change its form and more paradoxical propagated with a velocity 6–9 times greater than that of the light in vacuum c.

Let us now try to understand what was happened in the photonic experiments carried out by the propagation of light pulses through the amplifier and through the photonic barriers for determination of tunneling time and to answer the question: "Does the motion of photons across the amplifier or across the photonic barriers subluminal or superluminal?". Our theory answers this question: This motion must be a superluminal and it does not affront to the theory of special relativity and causality. Because, as it follows from the theory considered in the previous pages of the present paper, the theory of special relativity is applicable for the stationary (equilibrium) state in the region of drift velocities $u < c$. In the region of drift velocities $u > c$, the distribution function of photons is non–stationary and grows exponentially in time. At the point $u = c$ (at light instability threshold–LIT) as it follows from (20), the distribution function of photons is spherically symmetric one and it does not consist of any singularity and grows linearly in time. At this point the stimulated emission and absorption rates are the same and there is only spontaneous emission of photons at high external field. Moreover, the dissipation is absent and it is the point of stationary state. At the condition $u = c$, coupled system of carriers and photons emits all the power gained from the external field as photons (or electromagnetic waves) and as a result conserves the its stationary state. At this point the electrical current is constant and so the state is dynamically stationary one. Only from this point, the emission of electromagnetic waves by charge carriers begins under external electric field. As it follows from equations (7)–(9) only the part of photons with drift velocities $u < c$ are damped, the other part of photons with drift velocities $u > c$ are generated or amplified at external fields so they are undamped in the absence of external fields. As it was shown in our theory the so–called the speed of light in vacuum c is the average (by the frequencies) velocity of the pulse, or the velocity of photons with a frequency $\omega = \omega_{peak} = \overline{\omega}$, in the ground state. For other stationary states c is the average thermal velocity $\overline{v} = \sqrt{\overline{\varepsilon}/m} \approx \sqrt{T_i/m}$ of pulse Thus, only the subluminal (or subthermal) photons, $u < c$, at Planck's distribution function are interacting with the medium, but the superluminal photons, $u \gg c$, transmits into the medium freely without loss and the form of the pulse is conserved. This phenomena is independent of the type and the width of photonic barrier. This result represents a fundamental behavior of all the wave packets or light pulses in nature. Moreover, it shows that the tunneling processes are superluminal initially. There is no mysterious in the tunneling; the superthermal particles with energies (or frequencies) greater than the height of the barrier transmits the barrier region freely, because there is no barrier for them. Only the subthermal photons, frequencies with $0 < \omega < \overline{\omega}$, are reflected or damped through the process of interaction with barrier. It is well known there is no absolutely opaque barrier for all frequency region. The mediums which is opaque for the visible light is transparent for the region of Roentgen and Gamma rays. In other words, the medium which is opaque for low frequencies becames transparent for the high frequencies of photons. We found that the critical frequency is the average frequency of pulse or wave packet and obtained from the average energy or temperature of pulse. In the case when the light pulse propagates in vacuum or through in air, then the pulse propagates as a unit system, as a particle with energy (or frequency) $\hbar\overline{\omega}$ (or $\overline{\omega}$) and it does not change its form. All points of pulse propagates with the same velocity of the peak of pulse. In this case, the pulse propagates without interaction and for that reason conserves its form during the propagation.

In the case of the propagation of light pulse through the barrier, the pulse inter-

act with the barrier and splits into two pulse. The pulse of subluminal (or subthermal, damped), photons with drift velocities $u < \overline{v} \equiv c$ and superluminal (or superthermal, undamped) pulse of photons. While the subluminal pulse is reflected from the photonic barrier or damped, the superluminal pulse is propagates through the barrier without interaction and conserves its form. This theoretical consideration is confirmed by the photonic experiments[12, 21, 22, 28, 31, 34].

In the case of the propagation of light pulse in external electric and magnetic (or electromagnetic) fields, for example, through an amplified laser (see [12]), the pulse splits into two pulse, superluminal and subluminal. This can be seen visually. As these pulses propagates through the amplifier, the subluminal one is damped and the superluminal one is amplified. If the time interval Δt between the two acts of photons gaining energy from the external field is greater than the relaxation time of photons $\tau_{ph,ph}$ in the photon–photon scattering event, the pulse propagates without changing its form, but its amplitude must be increased. On the other hand, if $\Delta t < \tau_{ph,ph}$ then photons does not enough time to establish the equilibrium distribution of pulse with effective temperature, T_p. As a result, the form of the pulse should be changed and we have the case while the amplitude of the lower frequency part of the pulse will be decreased in time, the amplitude of the higher frequency (superluminal) part of the pulse will be amplified and finally we must have the high frequency half part of the initial pulse with amplitude growing in time[12].

Experiments with propagation of light pulse through the amplifying system confirms the theoretical picture stated above[12, 21, 22].

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